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Center for Superconducting & Magnetic Materials

MADISON CEC/ICMC 2017

REBCO Roebel cable stability, current sharing, and quench measurements in a LHe bath and applied magnetic fields of 12 Tesla

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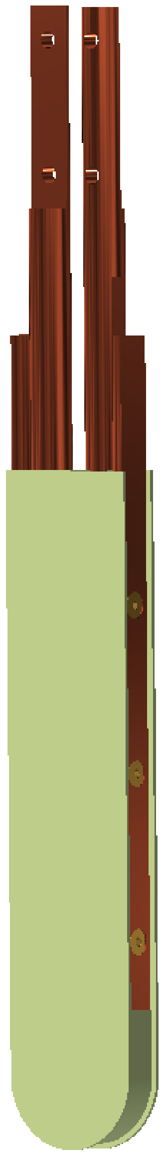
Motivation

- Previous measurements by Majoros et al. at 77K demonstrated high ICR and little current sharing without the use of soldered on copper splices.

- At varying I/I_c, and in different thermal environments and fields, measurements of MQE(?) and current sharing are desired.

- G-10 U-shaped holder
- Rated for 2000 A
  (PS Limit 1780 A)
- Tight fit in 60 mm bore research magnet.



Majoros et al. "Stability, Inter-Strand Contact Resistance, and AC Losses in YBCO Roebel Cables" *IEEE Trans on Appl Supercond 24, 3 (2014)*

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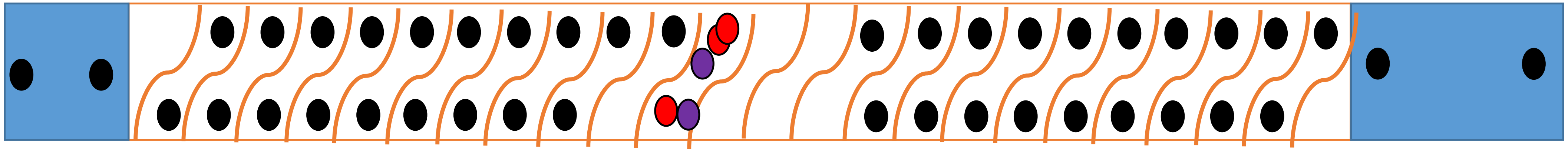
Sample and Instrumentation

Parameter	Specification
Roebel cable manufacturer	Karlsruhe Institute of Technology
ReBCO tape manufacturer	SuperPower Inc.
Type of Roebel cable	9/5.6
Cable Width, W_{Cable} (mm)	11.8
T_{tape} (mm)	0.1
$L_{Transposition}$ (mm)	126
Cross-over angle, φ (degrees)	40
$L_{Inter\text{-}strand\ gap}$ (mm)	0.4
$W_{Cross\text{-}over}$ (mm)	5.6

- Length of cable between solder regions: 355 mm
- Individual soldered tapes onto current tap region: 150 mm
- Wood's Metal Solder

● = Voltage Tap
● = Type-E Thermocouple
● = 40-Ohm Kapton Heater
■ = Soldered Current Tap



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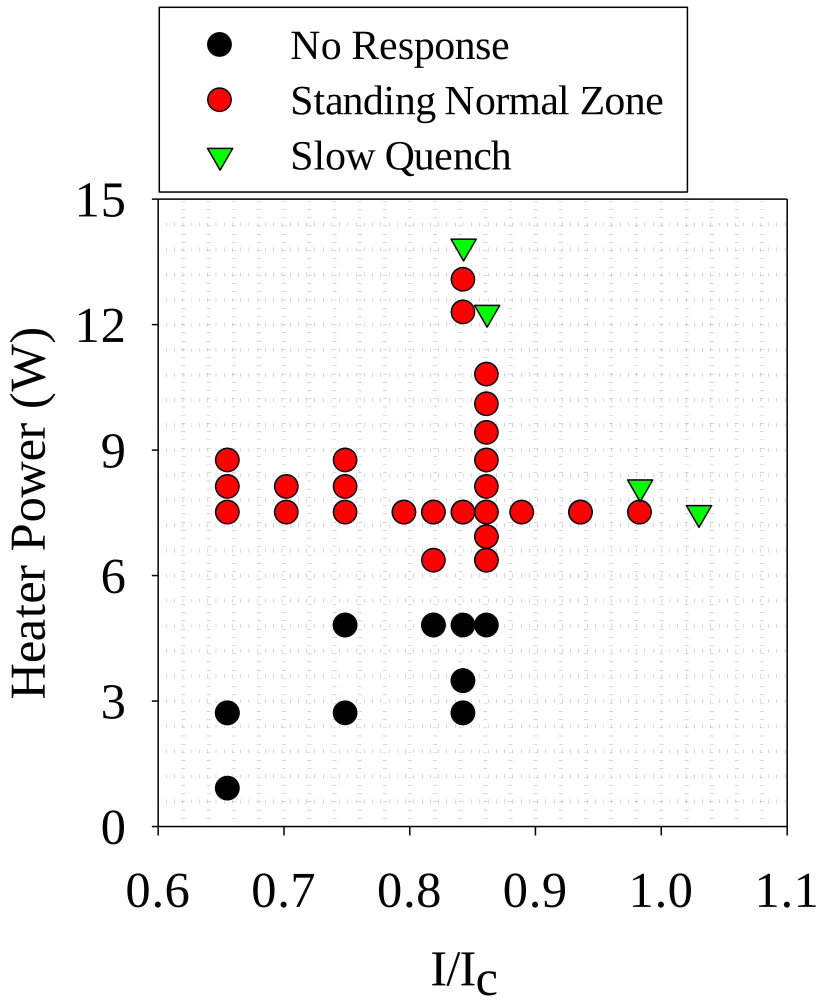
Quick aside: Self-field 77 K measurement

- Unimpregnated cable with individual tapes in good contact with LN_2
- A preliminary experiment was performed at varying I/I_c and heat pertubations.
  - I_c = 1068 A (10 uV/cm), I_q = 1130
- It was found that standing normal-zones could be created at I/I_c very close to 1. At I/I_c = 0.98, 8 W was required to slowly quench the cable.



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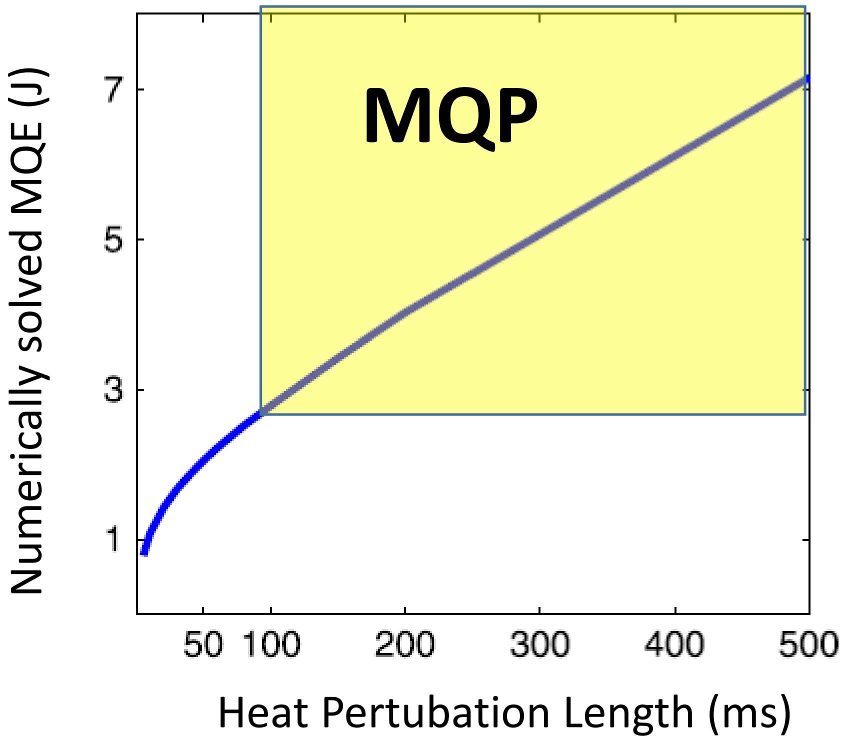
Quick aside: Self-field 77 K measurement

- Standing NZs was attributed to the very low Stekly number of 0.02; dominated by the fairly large P/A ratio of ~10000.
- Minimum Quench Power was appropriate to describe this quench behavior since heat perturbations had lengths of at least 100s of ms.
- Thermal stability and MQP has been suggested as the items of interest for HTS.

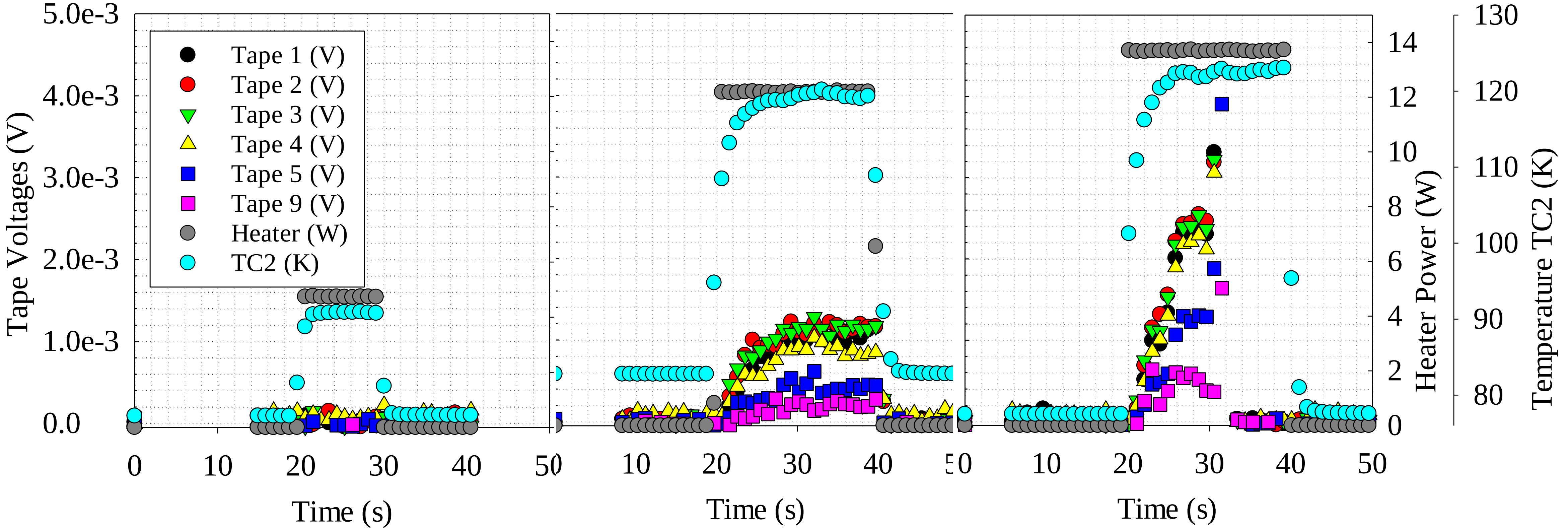


Awaji et al. “Hot Spot Behavior of Y123 Coated Conductors” *IEEE Trans on Appl Supercond 22, 3 (2012)*

Haro et al. “Modeling of Minimum Energy Required to Quench an HTS Magnet With a Strip Heater” *IEEE Trans on Appl Supercond 25, 6 (2015)*

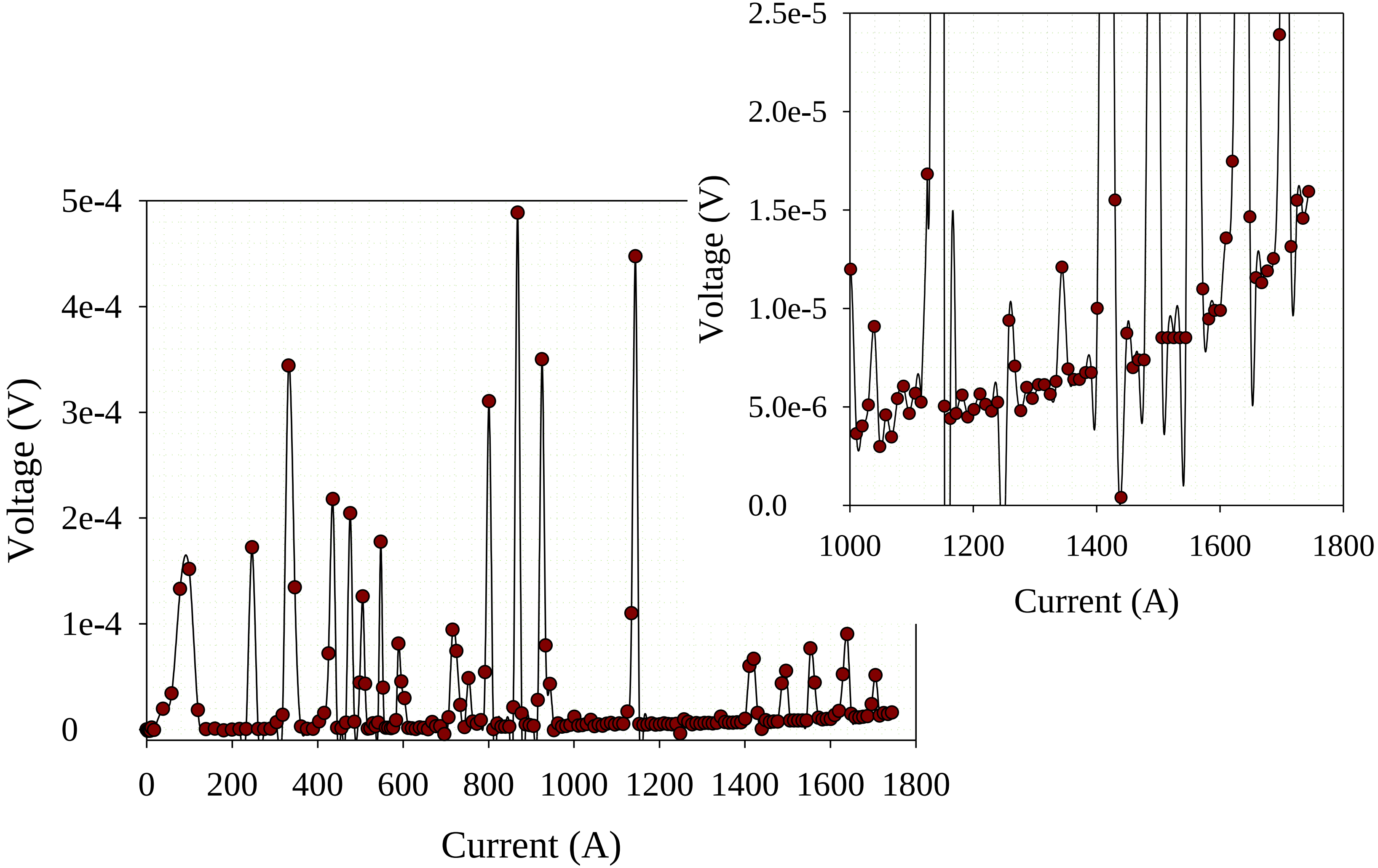
Quick aside: Self-field 77 K measurement

- Larger voltages generated in some, but not all, tapes signifies poor current sharing.



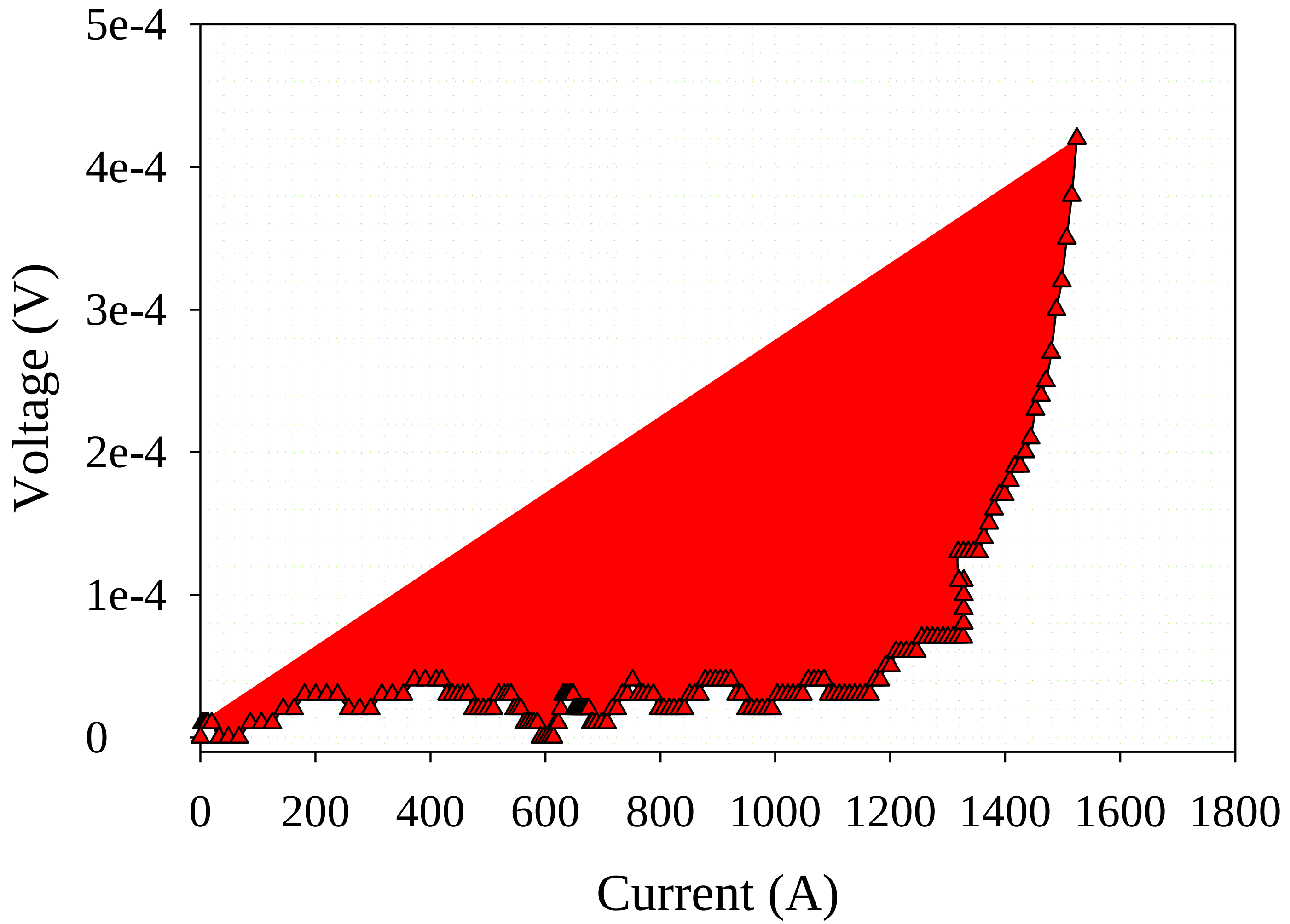
Impregnated Ic 12 T in LHe

- Sample was epoxy impregnated (Stycast 1266 w/ 50% weight Silica particles) and measured in a LHe bath at 12 T.
- I_c greater than 1780 A (PS Limit).
- Small voltage seen above 1200A; never reached criterion (10 uV/cm)



Impregnated 12 T in Lhe, Thermal Cap

- The same impregnated sample had a foam cap sealed with silicone adhesive.
- I_c of 1510 A, an I_q of 1530 A
- Sample burnt out with 20 mV quench limit (usually safe for our LTS samples)



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Impregnated 12 T in Lhe Thermal Cap

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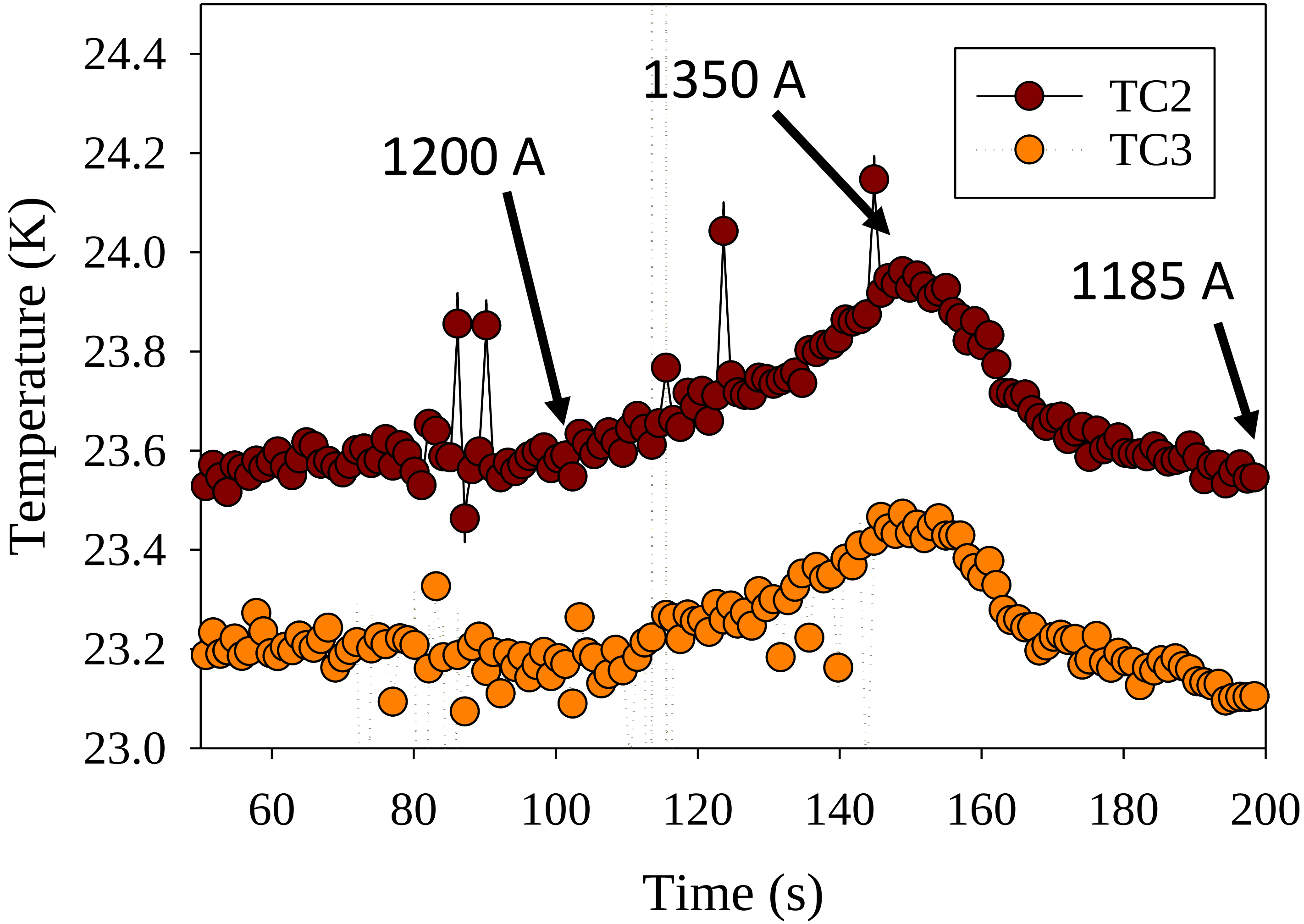
Why the Difference? Unimpreg vs Impreg

- Temperature increase was seen for impreg sample above 1200 A.
- Current decreased to 1185 A and 10 second heat perturbations , up to 8W, performed.
- No voltage signals detected during HPs.



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Thermal Conditions Discussion

- A steady-state power balance approach:

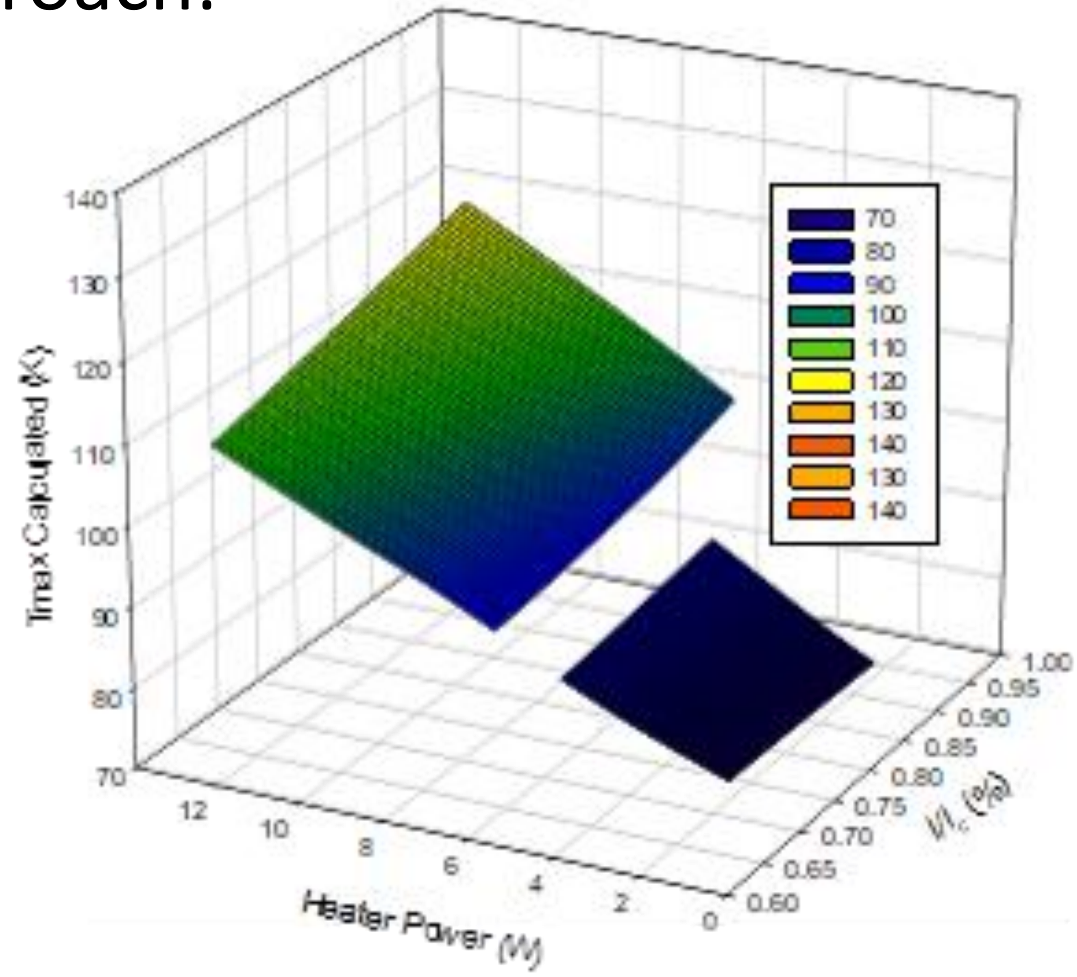
$$\left(\underbrace{2 \times k(T) \times A_{XS} \times \frac{dT}{dx}}_{Cond.\,Cooling} + \underbrace{Q(T) \times P \times X_S}_{Surface\ Cooling} \right)$$

$$\text{Cooling} = \text{Heating}$$

$$\left(\underbrace{\frac{\rho(T) \times X_N \times \left(I - I_c(T)\right)^2}{A_{XS}}}_{\substack{Joule\ Heating \\ I > I_c(T)}} \right) + P_{HP}$$

$$\frac{dT}{dx} = \frac{(T_{max} - T_b)}{X_C} \qquad Q(T) = h(T) \times (T_{max} - T_b)$$

$$\underbrace{min\left[\frac{\rho(T) \times X_N \times \left(I - I_c(T)\right)^2}{A_{XS}}\ or\ \frac{E_c}{I_c(T)}\left(\frac{I}{I_c(T)}\right)^{n-1} I^2\right]}_{Joule\ Heating}$$



Thermal Conditions Discussion

- Impregnation and Insulated decrease cold-end and surface cooling. (~1/10th the perimeter and smaller k(T))
- The power generated during initial n-transition for the impregnated and insulated sample drives thermal runaway in less time.

$$\underbrace{\frac{\partial T}{\partial t}}_{Rate\ of\ change\ T} = \frac{\text{Joule Heating} + P_{HP} - \text{Cond Cooling} - \text{Surface Cooling}}{C(T)}$$

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Conclusions

- Thermal stability (MQP) will likely be the item of interest for HTS.
- At 77 K it is possible to generate stable normal-zones at high I/I_c because of the very low Stekly number of a non-impregnated Roebel cable.
- The I_c at 12T and 4.2 K was smaller for a thermally insulated sample even though n-transition began at same current.
- Current sharing was negligible in all Roebel samples at 77 K and 4.2 K.